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STRUCTURAL CONSIDERATIONS FOR THE RECOVERY OF AIR-TO-AIR MISSIL--ETC(U)
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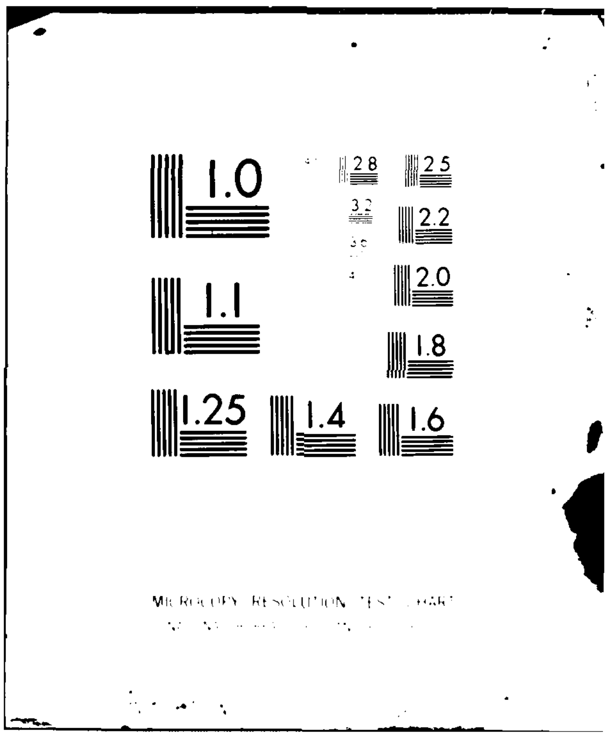
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STRUCTURAL CONSIDERATIONS FOR THE RECOVERY OF AIR-TO-AIR MISSILES

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ABSTRACT

The recovery of air-to-air missiles for training and evaluation is a cost and asset saving technique for consideration of the missile community. Cost, environmental, logistic, and physical constraints require decisions that complicate the structural designers task. Some considerations for design are discussed. An example showing possible trade-offs is given. A discussion of structural considerations is then followed by concluding statements.

INTRODUCTION

The recovery and reuse of air-to-air missiles, expended in testing and training environments, has long appeared to be a cost effective means for training capability and utilization of the weapon as well as providing the potential to accurately determine the causes of missile in-flight failures. Many studies have been conducted to analyse the technical feasibility and cost effectiveness of recovering missiles for reuse (references 1-2). The AIM-7 and AIM-54 missiles have been considered as prime candidates for consideration.

Many technical problems have been defined in considering the addition of recovery capability to an existing missile. Cost of course, is the limiting factor. Issues driving technical considerations include: (1) land/water/mid-air recovery, (2) anticompromise, (3) full vs partial missile recovery, (4) water integrity, and (5) use envelope of launches.

STATEMENT OF INITIAL CONDITIONS

For this paper the purpose for a parachute recovery system can be defined as: "a capability to reduce the velocity of a post-intercept missile to some acceptable amount low enough to allow retrieval of it for reuse."

Before a recovery system for a missile can be postulated, it is necessary to determine a use envelope of launches for both training and test and evaluation shots. Within that envelope an acceptable scenario can be generated for both training and test and evaluation. This has an important limiting effect on the design. Realistic decisions by the "user" can allow the designer sufficient flexibility to produce a more efficient/cost-effective product. For instance; if for training purposes a significant number of missiles, say 80-90 percent are to be fired at a mid-altitude, mid-range, mid-speed condition, then this should be specified. Design compromises are therefore more realistically made. An appropriate method for interpreting a given aircraft/missile launch envelope is to generate a scenario of launch geometries suitable for

training and/or RDT&E missions.

In order to construct a scenario of recoverable launch geometries for future Fleet training exercises and future T&E launches, a study of expected Fleet threats and a review of all past T&E launches should be made. Future Fleet training launch geometries must be designed around probable enemy threats. Air Test and Evaluation Squadron Four (VX-4) can supply data pertaining to expected enemy threats to the Fleet and beach head defense situations and has compiled this data in their report "FPX-2E". This classified report describes the threats as single bombers, multiple bombers, air-to-surface missiles (ASM) air launched, ASM surface launched, overland fighters, manuevering targets and the high altitude, high Mach threat. Target altitudes can be broken down into general categories; low (1,000 feet), medium (5,000 to 30,000 feet), and high (above 35,000 feet). Target speed and maneuvers can also be defined. Using the above criteria and prioritization criteria such as might come from the Ault Report (reference 7), threat profiles can be established against which future Fleet training launches can be designed.

Given a list of profiles, a table of launch geometries can be compiled and submitted to aerodynamists for post intercept parameter calculations. From the post intercept parameter calculations, worst case recovery conditions can be determined. To determine the worst-case recovery conditions, that is the geometry which would cause the most stress to the deploying parachutes, the post intercept parameters can be used to calculate the dynamic pressures (q) of individual geometries as follows:

dynamic pressure (q) = $1/2 \; P \; V^2$

P = air density at recovery altitude

V = missile velocity at recovery (ft/sec)

Given the initial loading conditions at intercept, the design problem of a recovery system can be addressed. This entails the designing of a parachute system to fit those load conditions and the load conditions at impact (water or land). The missiles structural integrity and its components resistence to shock and vibration are a limiting input to the parachute system design at this point.

CONSIDERATIONS OF POSSIBLE SOLUTIONS:

One of the first problems to be considered in the design of a recovery system is the question of a need to recover over both land and water. If over land, the missile terminal velocity and attitude at touchdown can be critically limiting to the design. If over water, terminal velocity and attitude are less critical but salt water integrity is required for most of the internal parts of a missile. One solution to both land and water recovery problems is MARS, a mid air recovery system. This is a complicated and costly solution. The logistics and expense of mid-air retrieval usually procludes its use except for unusual circunstances.

For over-land recovery, a very low terminal velocity or a cushioning device will probably be required. The TOMAHAWK missile solved this problem for recovery of test and evaluation shots by use of an inflatable air bag below a horizontally suspended airframe.

For over-water recovery, a flotation device must be incoporated to insure that a retrieval attempt can be made. Also required would be a device to insure that the floating missile would sink after some predetermined time because of security considerations. If the missile is suspended vertically by the parachute lines to enter the water nose first, a high terminal velocity could allow the missile to penetrate the water to below its crush depth.

Another problem to consider for a recovery system is whether the whole missile need be retrieved. The usual method for packing a recovery system in a missile is as a replacement for the warhead section. If only the empty motor, skin and wings are aft of the warhead section it would probably not be economic to recover the entire missile. Parachute deployment becomes simpler with this condition.

Still another problem to consider is the possibility of a slow down maneuver by directing the missile to climb to bleed off speed. The state-of-the-art of parachute design is limited in the supersonic region. Also, very low altitude recovery may require this maneuver because of a lack of time to impact for a recovery system to deploy.

Postulation of a Recovery System

A recovery system for a specific missile, such as the PHOENIX AIM-54, could probably be limited to over-water recovery since most testing and training shots occur over the ocean and most likely at a sea test range for control and data retrieval purposes. Consider the size, strength and volume of the recovery systems required to decelerate either the forward section of the PHOENIX or the total PHOENIX missile. The forward section includes the radome, the seeker, and the guidance section, and part of the warhead section. The total missile includes, in addition to the forward section, the spent motor section, the control section, and part of the warhead section.

To determine if both PHOENIX configurations can be recovered, consideration must be given to the total parachute systems. Deployment reliability, volume required for ejection mechanisms, volume required for the parachute and deployment complications associated with recovering the entire missile, all influence a decision as to recoverability. Factors to consider are: (1) recovering the forward section only allows for a traditional, unobstructed rear streaming flow of the parachute. Loads are longitudinal and do not impart pitching or tumbling motions to the missile (figure 1); (2) to recover the entire missile, the parachute system is more complicated (figure 2). First, dual drogue chutes are required to prevent the missile tumbling [illegible] which would be induced if only one drogue were used. Then a large section of the missile's skin must be cut and removed to allow the main parachute deployment bag to exit. At least one-half the circumference of the body skin would need to be removed which would seriously weaken the fuselage. Structural failure could result when the main chute opening force is applied. When recovering only the forward section, danger of rotation or tumbling of the missile; thereby fouling the parachute, is removed. Tumbling will not be induced since the deployment force is along the missile's longitudinal axis, which ensures a stable deployment.

Regardless of which configuration is selected for recovery, the volume available for the parachute system is the same. Approximately 1,475 cubic inches are available for the parachutes, the mortars, the timers, the flotation gear, and the locator beacons. The defined terminal rate of descent is 65 ft/sec

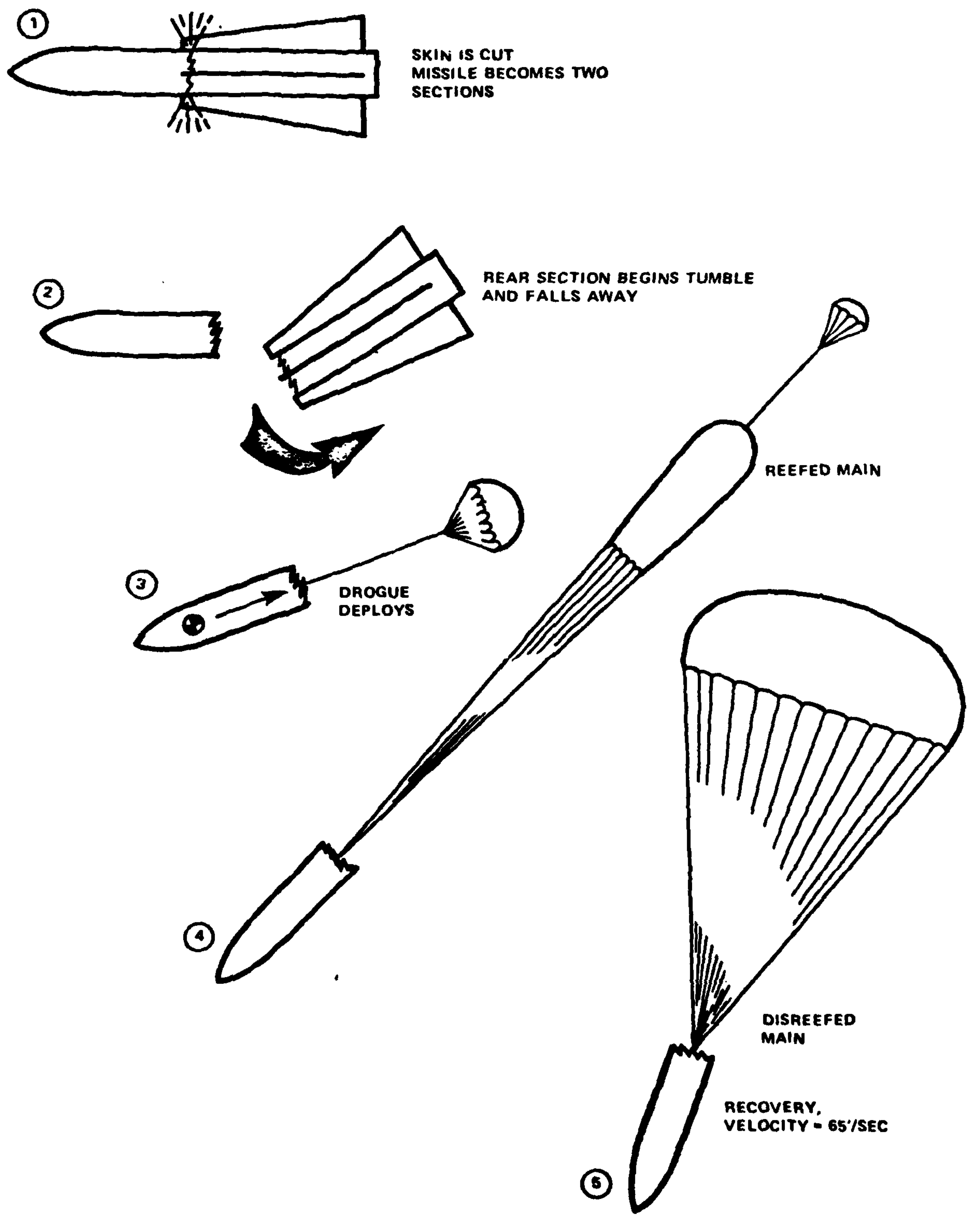

Figure 1. Parachute Deployment Sequence (Forward Section).

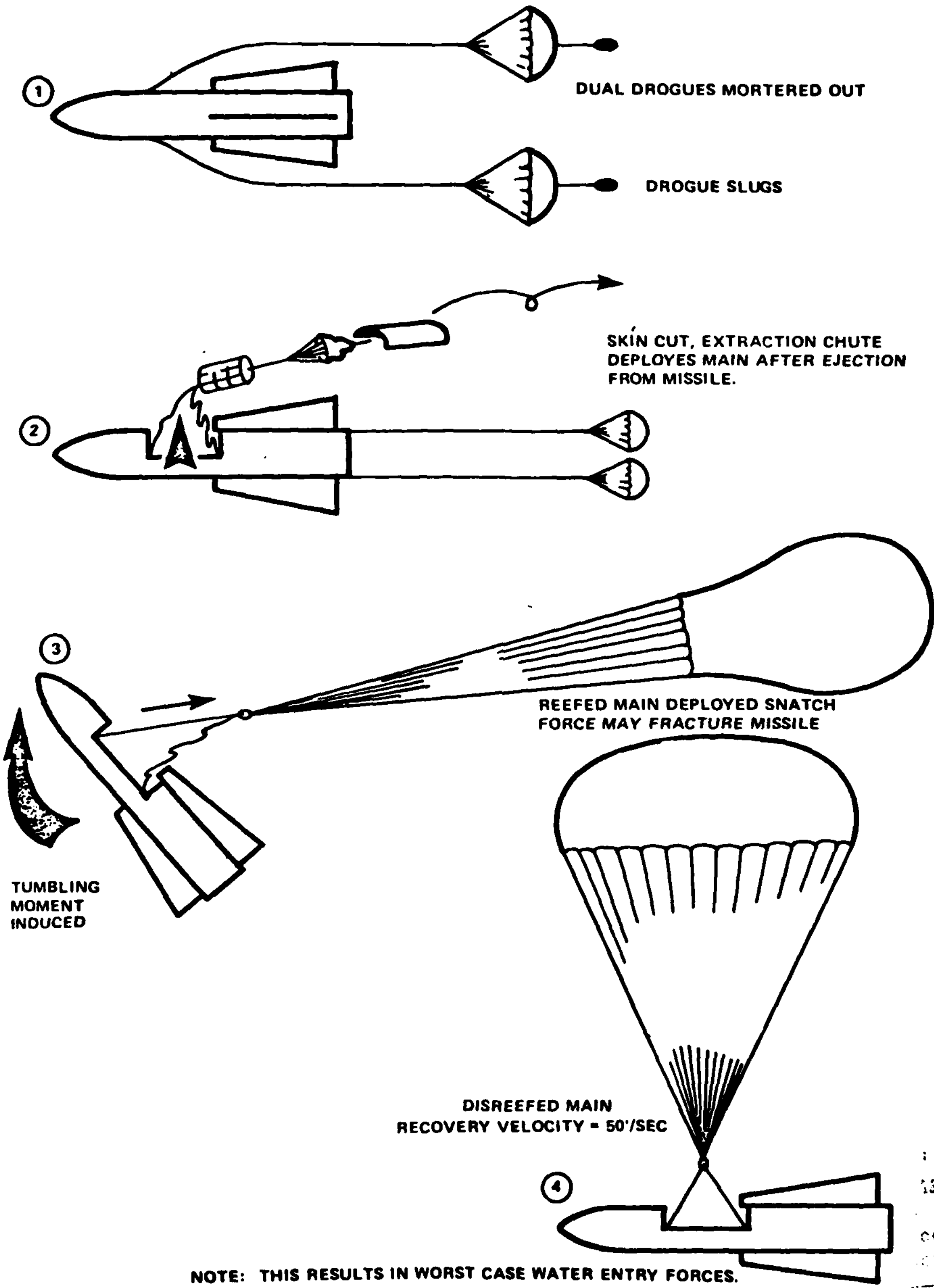

Figure 2. Parachute Deployment Sequence (Full Missile).

for either system. The forward section weighs 290 pounds while the entire missile weighs 545 pounds at recovery. A larger diameter parachute constructed of stronger material is required to lower 545 pounds at 65 ft/sec than to lower the 290 pounds at the same rate of descent. There would be sufficient volume to containe the parachute for the full missile recovery system but not the space to also include the drogue mortars and flotation gear. These details must be considered when making a decision as to which configuration is to be recovered.

A parachute recovery system could be designed for both missile configurations. The designs would be based on standard parachute design practices as described in the handbook (reference 4). Basic calculation methods since that date have not changed.

In order to calculate parachute size and strength, some assumptions have to be made. The assumptions are consistent between systems and would include the following:

Recovery velocity
Recovery altitude
Initial missile pitch angle
Recovery dynamic pressure
Maximum terminal velocity
Weight of forward section
Weight of entire missile

The basic equation used in calculating a theoretical parachute size and force is:

$$F = q\ C_{D_o}\ S$$

where:

F = force or the weight recovered in pounds

q = dynamic pressure (lbs/sq.ft)

C_{D_o} = drag coefficient of the parachute type (.75 for a solid flat canopy)

S = the parachute area (usually flat canopy size) in sq.ft

Using equation (1), the parachute diameter required for the 65 ft/sec terminal velocity rate of descent in recovering the front section only can be calculated.

The drogue chute selected would be a ribless guide surface design of small diameter.

Initial force calculations could indicate that an unreefed main opening would exert excessive force on the parachute mounting points as well as damaging components in the missile. Therefore, the main canopy could be reefed to an effective diameter for a required time period. This reefing (restricting the full open diameter of the main chute by lacing a constricting line through the skirt) will allow a reduction of velocity while a smaller drag area is exposed to the higher "q" conditions. The force is directly proportional to the velocity and the drag area. By adjusting the reefing line length, a balance of forces

can be achieved between reefed open (smaller drag area) and full open; thus allowing the missile and parachute structure to see a lower peak force. The three stage recovery system for the forward section is defined as:

1. The drogue chute
2. The reefed main
3. The disreefed main

The force/time history of the deployment might be such as shown in figure 3. The curves connecting the inflection points are estimated shapes as there is no program available to derive exact force or time values during inflation periods and deceleration to equilibrium velocities. In order to determine the forces during the various sequences of deployment, it would be necessary to know the system velocity, altitude, and pitch angle at the appropriate events. To assist in these calculations, a set of parametric trajectory curves and nomographs can be used. They can be found in ASD-TR-61-579 (reference 4). By knowing the initial velocity (V_o) and pitch angle (θ_o) and the required equilibrium velocity (V_{eo}), the following values may be found graphically: system velocity at a delta time after initialization (V), altitude loss (H), range (R), and a new pitch angle after delta time (t). By obtaining the velocities (V) and new altitudes at each deployment event, the force can be calculated using equation (1). With these data, a force/time histograph can be made.

The method of calculating the required data for the total missile recovery is the same as defined above. A typical force time histograph is included as figure 4.

With the above information as postulated it would now be possible to evaluate the structural integrity of a recovered missile (either the full missile or the partial front end section).

DISCUSSION OF STRUCTURAL CONSIDERATIONS

The structural integrity can be determined for the two critical events in the recovery sequence, the deployment shock and the water entry forces as compared to the missiles capability to resist those loads.

For the deployment shock a preliminary analysis of loading conditions can be investigated for the recovery. Two main concerns are:

1. Structural integrity of the parachute attachment design; and,

2. Responses of the guidance section to the loadings.

A structural model such as the Hughes Aircraft Company finite element model (reference 5) of the missiles' two forward sections can be used for this analysis. In order to have the proper weight and load path, the model would include the guidance section skin, bulkheads at both ends, radome and parachute installation container. Figure 5 shows the general arrangement of the recovery system. Figure 6 depicts the structural model.

The model has 74 beams and 411 plate elements. The Guidance section skin can be simulated by a beam connecting two nodes representing the bulkheads. Seeker and radome can be lumped as a single mass cantilevered from the bulkhead.

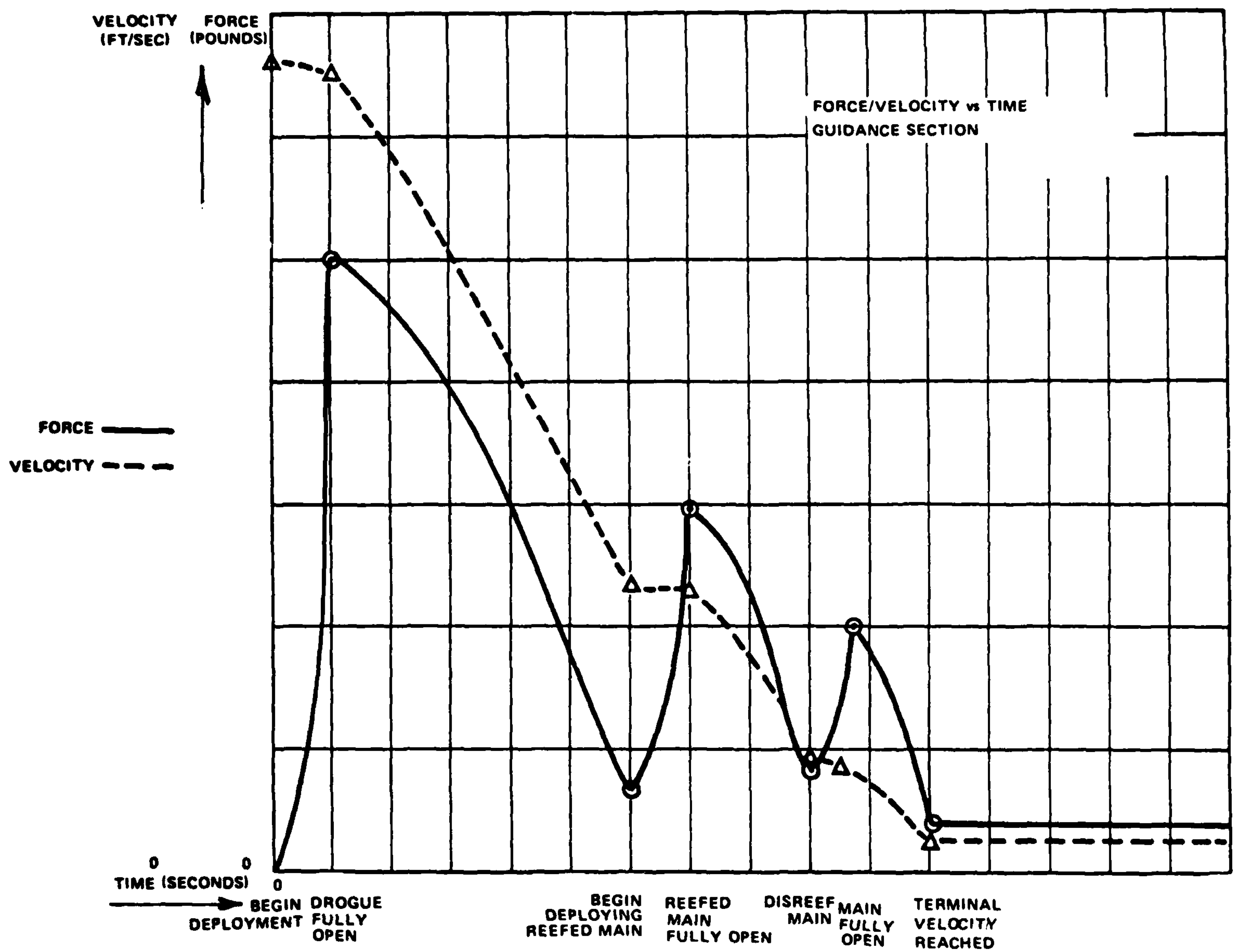

Figure 3. Guidance Section Force/Velocity vs Time.

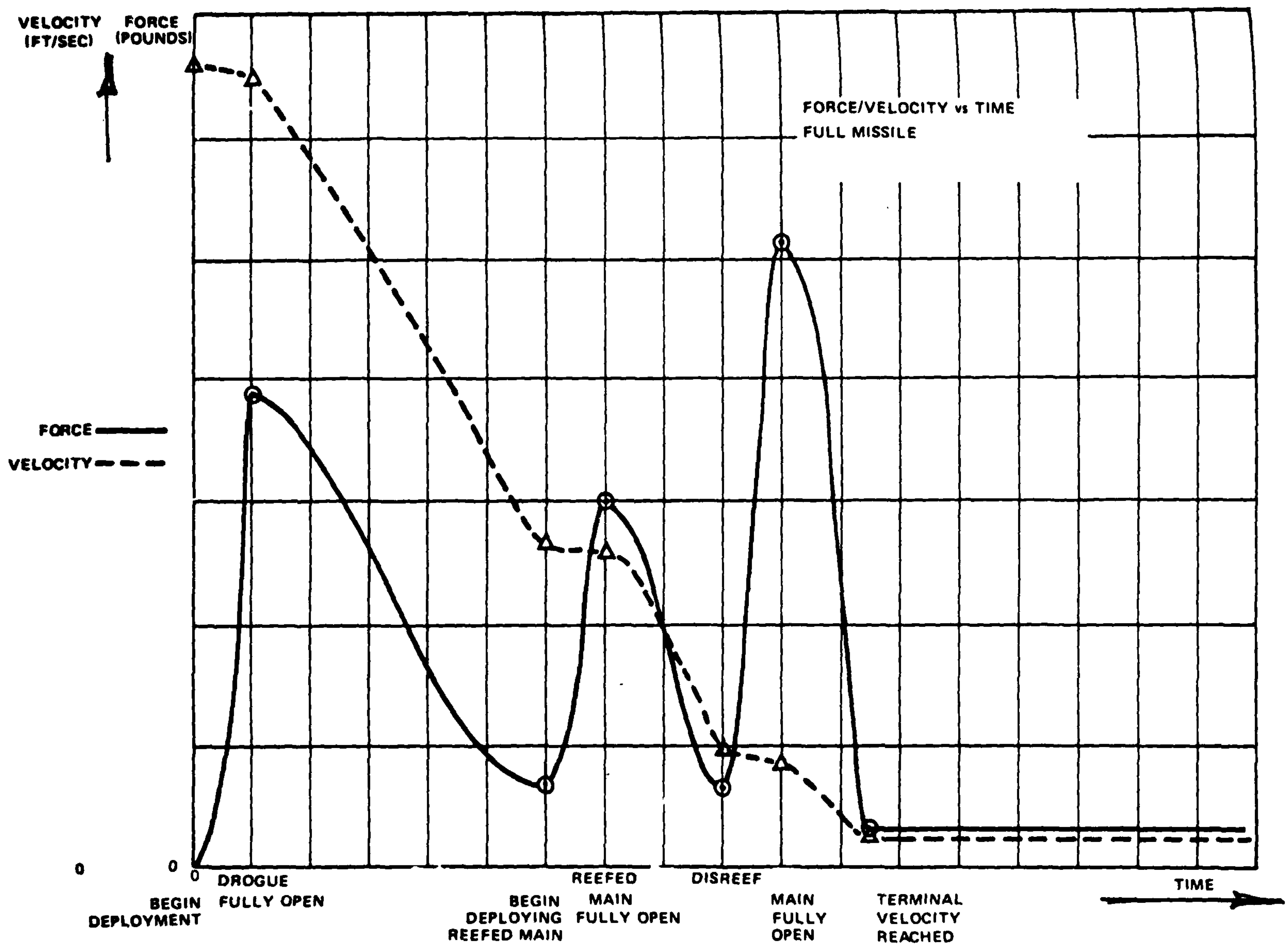

Figure 4. Full Missile Force/Velocity vs Time.

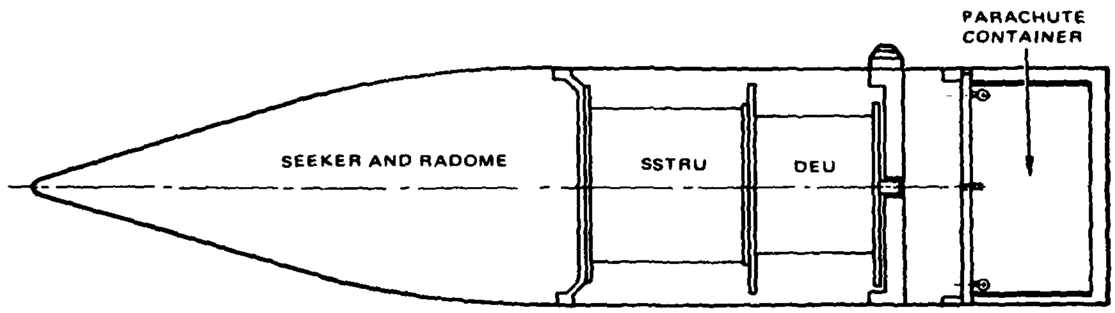

Figure 5. Recovery System

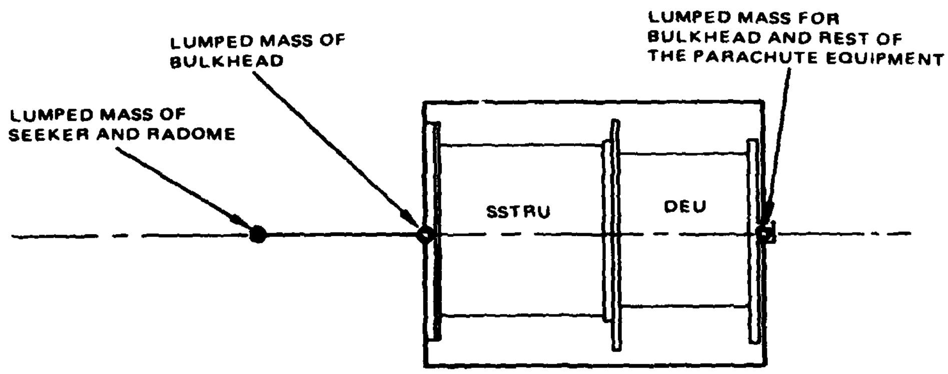

Figure 6. Model for Response Study

Parachute opening loads are applied at the rear end, while water entry loads are at front end of the section or at both ends when there is a lateral component. The proper loading orientations are shown in figure 7. Figures 8 and 9 are typical time-acceleration histories of the parachute opening and of a 20 degree water entry impact.

Parachute opening shock is critical for the parachute supporting bracket (see figure 10). If four brackets are considered to carry the total load and a 1.5 factor is a shock factor, then the strenth of each spot weld tying the bracket to the skin can now be found. Assuming an even loads distribution, the number of welds needed for each bracket can be determined.

The missiles can be evaluated for structural integrity with water entry at 20^{o} or less from the vertical. The missile responses to the two shock inputs (both parachute opening and water entry) can thus be studied. A similar investigation can be performed for the full missile recovery situation.

After water entry, the guidance section attached to a parachute, will descend into the ocean. Analyses can be performed to determine the deceleration, velocity, depth and pressure experienced by the guidance section during penetration. The effect of orientation on penetration can also be examined.

Typical forces acting on the guidance section after water entry are shown in figure 11. The resulting equations of motion are:

$$M\ddot{X} + Mg - F_B - F_H = 0 \quad (1)$$

$$F_H = C_D \, 1/2 \, P\dot{X}^2 A \quad (2)$$

where M = guidance section mass

F_B = buoyant force

X = penetration depth

F_H = hydraulic forces retarding motion

C_D = drag coefficient

P = density of water

A = cross section area

The equations were solved for X (and its derivatives) using a quasi-static approach, i.e.

$$X_j = \frac{C_D \, \rho A \, \dot{X}^2_{j-1}}{2M} + \frac{F_{Bj-1}}{M} - g$$

$$\dot{X}_j = \dot{X}_{j-1} + \ddot{X}_J \quad t$$

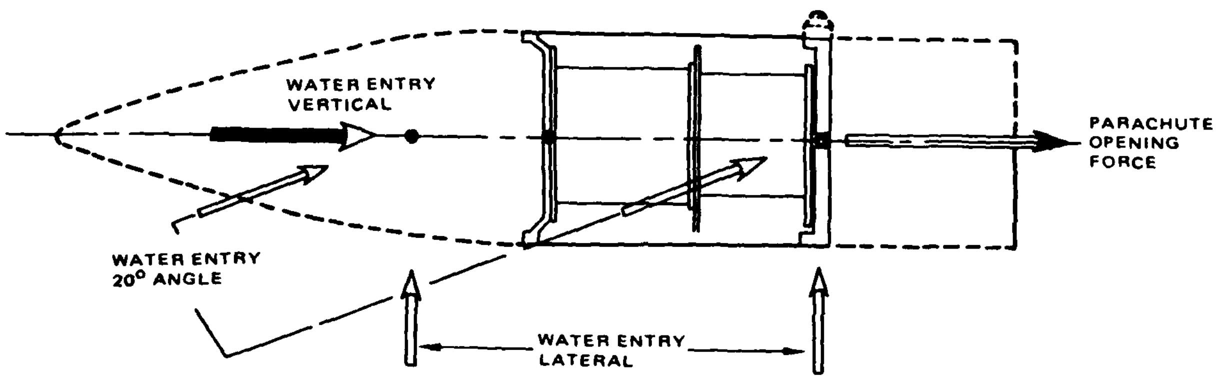

Figure 7. Loading Convention of the System

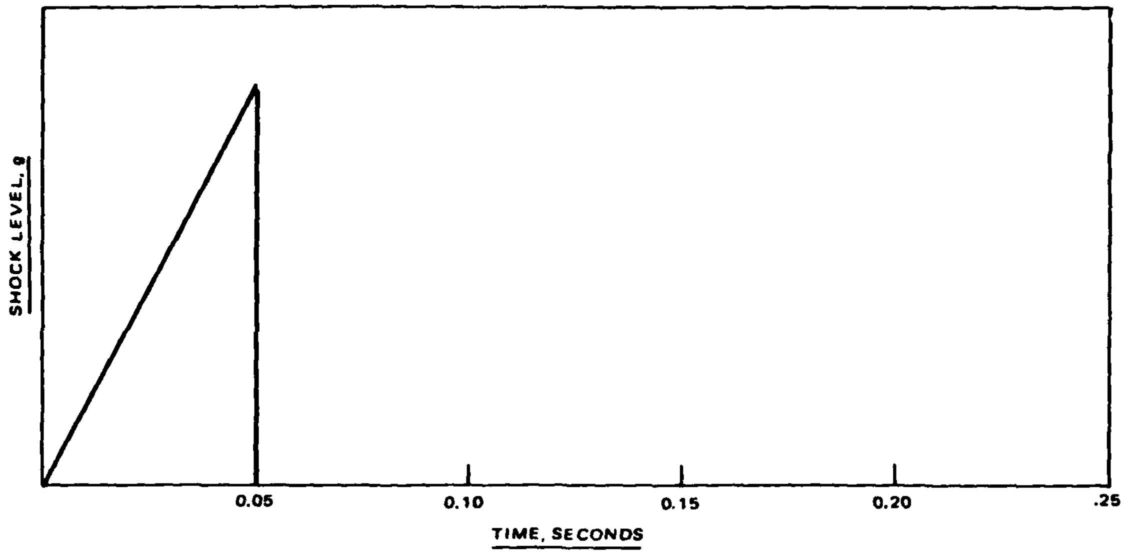

Figure 8. Parachute Opening Shock

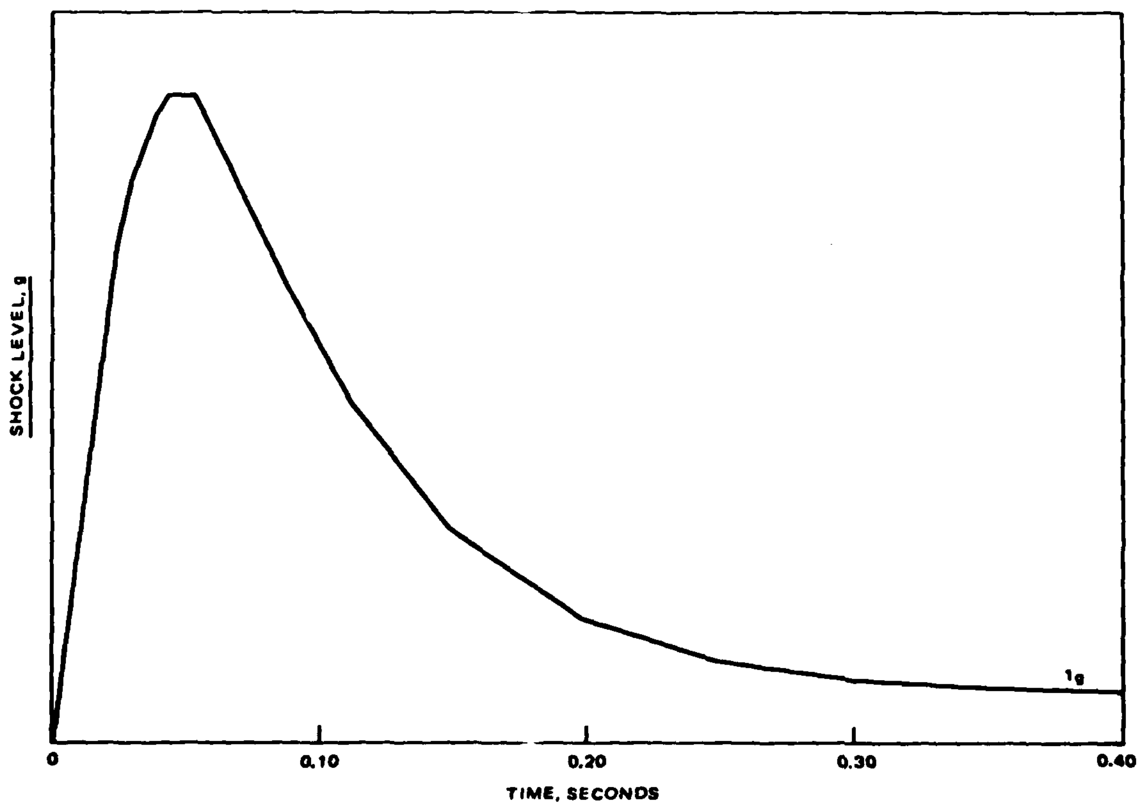

Figure 9. Water Entry Shock, 20 degree Angle

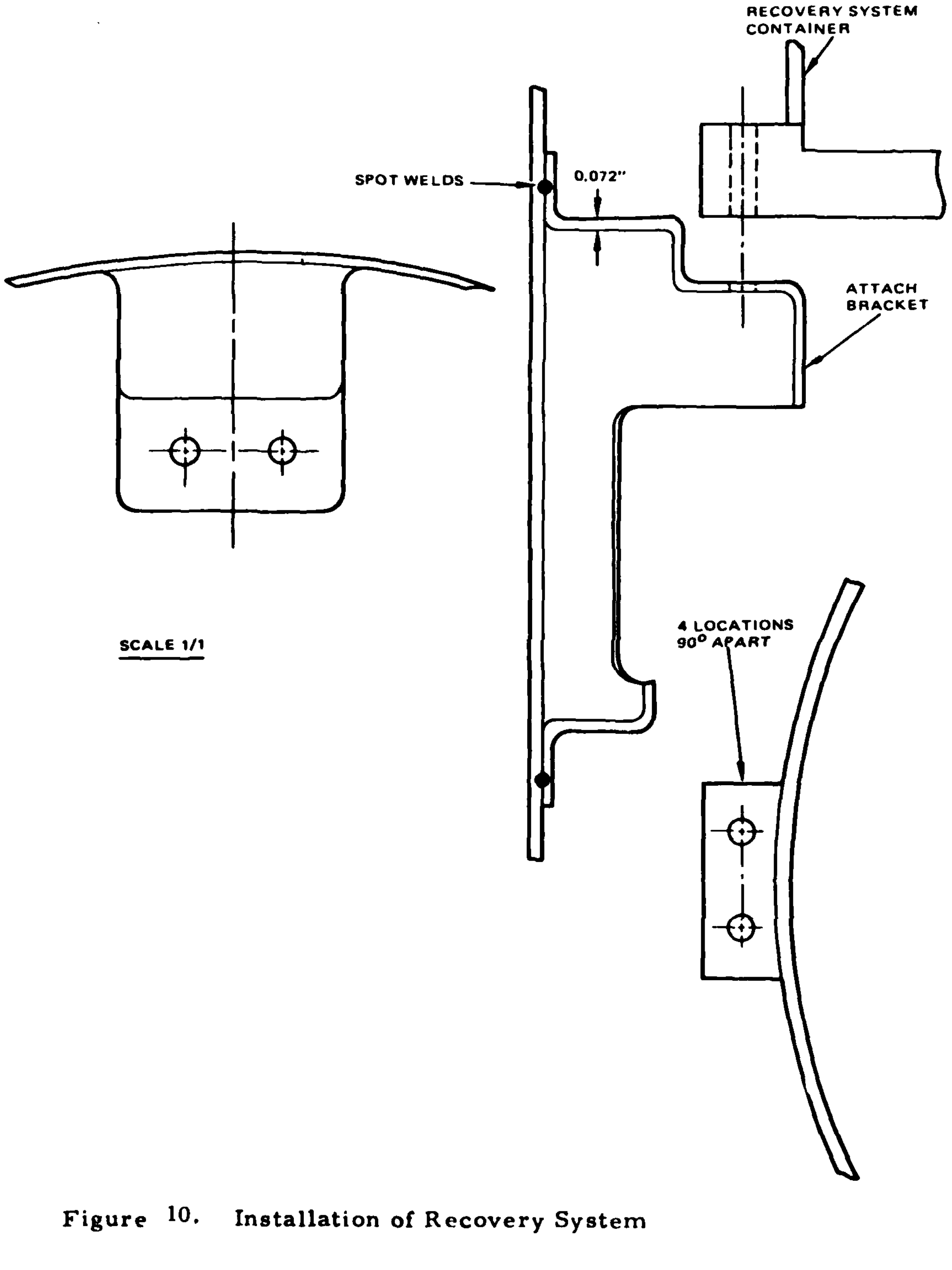

Figure 10. Installation of Recovery System

$$X_j = X_{j-1} + \dot{X}_j \quad t$$

j = current time step

t = time increment

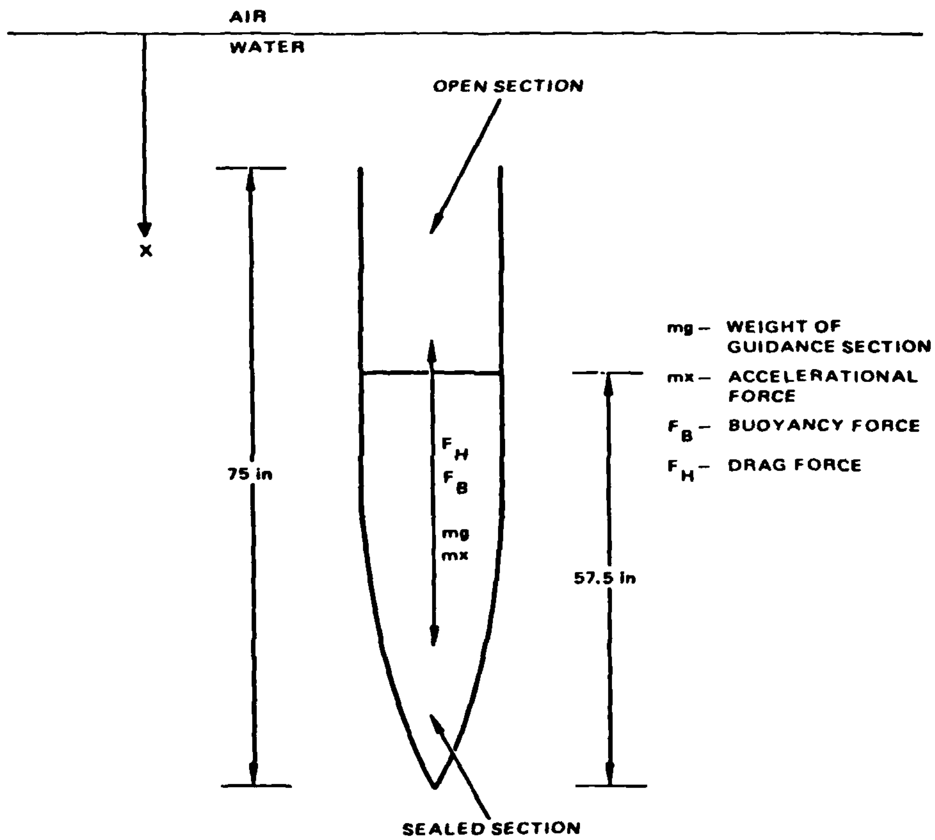

Figure 11 Guidance Section and Partial Armament Section

The guidance section and partial armament section is composed of a sealed section and an open section. During penetration, the buoyancy force increases as the unit submerges and reaches a maximum value just prior to complete submergence. Upon complete submergence, buoyancy decreases to that of the sealed section as water fills the open section. Conservative values for penetration depths can be obtained by using buoyancy forces associated with the sealed section alone. Conservative deceleration values can be obtained by using the buoyancy of the entire unit.

Winds acting on the unit during descent may cause the guidance section to strike the water at an angle. Significant increases in deceleration can be expected from such penetrations. Therefore, analyses which considered orientation angles such as 20 and 90 degrees (measured from vertical) can be performed to determine the effect of orientation on deceleration. In an analysis, orientation manifests itself in the drag coefficient; the cross sectional area used in determining drag force, and the manner in which buoyancy force is computed as the body is entering the water. Orientation angles can be kept constant during the entire penetration calculation.

In an analysis considering 20 and 90 degree orientations, hydraulic forces are linearly increased to their full value as the unit enteres the water. Buoyancy forces for a 20 degrees orientation are similarly increased. However, for a horizontal penetration a function relating volume displaced by a cylinder should be used to determine buoyant forces. The forces on the missile can thus be calculated and compared to its skin's capability to resist these crushing forces.

CONCLUSIONS

The structural adequacy of a missile, redesigned to be recovered after launch, can be determined on a case by case basis using the existing structural analysis techniques.

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